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ABSTRACT

This unit is one of a group of units written to fit the Certificate of Sixth Year Studies (CSYS) chemistry course, but it could be used with most Sixth Form courses. It includes: (1) background information for teachers with notes on five topics (antifreeze, ethanol production, solvent prices, iron extraction, and paint solvents); (2) a student information packet, with introductory comments and suggested activities for each of the five topics; and (3) an oversized reference chart listing properties of various compounds. The topics were chosen to integrate the course material with the world of chemistry outside the classroom and the discussion takes into account such factors as economics and safety as well as purely chemical factors. (DH)

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ORGANIC LIQUIDS CONTAINING OXYGEN

This unit is one of a group of units written to fit the Certificate of Sixth Year Studies course but could certainly find a place in most Sixth Form courses.

The series has been written by a group of teachers, college lecturers, university lecturers and industrialists.

It has been supported financially by the Education Appeal Fund of the Royal Society of Chemistry and the Education for the Industrial Society Group of the Scottish Curriculum Development Service and has received the approval of the Chemistry Panel of the Scottish Examination Board.

It is hoped that this will be used in an interactive way to give pupils the experience of making decisions for themselves on the basis of their chemical knowledge and the knowledge of other disciplines, so that they may truly see that the decisions of chemical industry are of necessity - multi disciplinary.

We realise that this unit will not be perfect and we would welcome helpful criticism so that later editions can be improved.

Dr. A.H. Johnstone
General Editor.

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ORGANIC LIQUIDS CONTAINING OXYGEN

Teachers Copy

APPLICATIONS OF ORGANIC LIQUIDS CONTAINING OXYGEN

General Introduction

Like others in the set, this package is intended to provide the basis for a discussion by CSYS pupils and their teachers of the wider aspects of a topic from the syllabus.

The topics have been chosen to integrate the course material with the world of chemistry outside the classroom and the discussion takes into account factors which apply there, including economics and safety as well as purely chemical factors.

In this package the pupils are provided with a table of data about the properties of some alcohols, acids, esters, ethers, ketones etc. and are asked to discuss and make decisions on several problems where such compounds might be involved. Course work and general knowledge as well as the data in the table may be relevant to the discussions. The teacher is provided with some supplementary information which is not intended to provide the "right answer" but rather to help guide or summarise the discussion and he may participate in the discussion at whichever stage he choses. Study of the problem and the data by pupils before the discussion might be profitable. The class might be divided into small groups, each to discuss and decide on one of the problems and then to present their arguments and conclusions to the others.

TEACHER

APPLICATIONS OF ORGANIC LIQUIDS CONTAINING OXYGEN

Introduction.

This supplement contains references and extra information which may help guide the discussions.

Similar teacher sheets (all green) go with each discussion topic.

Data Table

The physical data were obtained from -
'Organic Solvents' by Riddick and Burger in the "Techniques of Chemistry" Series, A. Weissberger (Editor), John Wiley and Sons, 1970.

The toxicity data were obtained from -
'Hazards in the Chemical Laboratory', L. Bretheric (Editor), Royal Society of Chemistry, 1981.

other reference books include -

'Dangerous Properties of Industrial Materials", Sax, Van Norstrand.

'Handbook of Reactive Chemical Hazards',Bretheric, Butterworths.

'Hazardous Chemicals', SSSERC, Oliver and Boyd.

The TLV is only one assessment of toxicity, relevant only to gases, vapours and powders dispersed in the air. Different assessments would be made for toxicity by skin contact, ingestion or injection.

The rough relative prices quoted are per tonne for bulk industrial quantities and may not correlate with prices for a few litres which are much affected by handling and bottling costs and tax on ethanol and petrol equivalents.

MISCIBILITY OF ORGANIC SOLVENT PAIRS

All pairs are miscible unless marked 'X'.

	water	methanol	ethanol	propanol	butanol	cyclohexanol	ethanediol	propanetriol	ethanol	propanone	butanone	methylpentanone	cyclohexanone	ethanoic acid	ethyl ethanoate	methylbutyl ethanoate	diethyl ether	diisopropyl ether	tetrahydrofuran	dimethoxyethane	hexane	toluene
water					X	X					X	X	X		X	X	X	X			X	X
methanol																					X	
ethanol																						
propanol																						
butanol	X																					
cyclohexanol	X																					
ethanediol											X	X	X		X	X	X	X			X	X
propanetriol										X	X	X	X		X	X	X	X		X	X	X
ethanal																						
propanone								X														
butanone	X						X	X														
methylpentanone	X						X	X														
cyclohexanone	X						X	X														
ethanoic acid																						
ethyl ethanoate	X						X	X														
methylbutyl ethanoate	X						X	X														
diethyl ether	X						X	X														
diisopropyl ether	X						X	X														
tetrahydrofuran																						
dimethoxyethane								X														
hexane	X	X					X	X														
toluene	X						X	X														

The classifications were made at 20°C in the following manner.
1 ml portions of each solvent comprising a pair were shaken together for approximately a minute. If no interfaced meniscus was observed after the contents of the tube were allowed to settle, the solvent pair was considered to be miscible. If a meniscus was observed without an apparent change in the volume of either solvent the pair was regarded as immiscible. (Reprinted from the American Chemical Society).

TEACHER

Anti-Freeze

The freezing point depression (ΔT_f) for a solute obeys the equation $\Delta T_f = K \times m$ where K is a constant, characteristic of the solvent and m is the number of moles of solute per kg of solvent. (i.e. per litre in the case of water). For water, a freezing point of $-18^{\circ}C$ is achieved when the solute concentration is about 10 moles per kg. The weight of solute needed to achieve this will be proportioned to the molecular weight. Low M.W. solutes will be most effective per gram. Low M.W. alkanols are very soluble in water and are unreactive. Methanol and ethanol are rather volatile and have relatively low flash points. Ethane-diol has a low flash point, low M.W., and is very soluble, but is more viscous, and more expensive than methanol. Ethyl ethanoate is insoluble in water. Propanone and propanol are soluble and have fairly low M.W. but also low flash point and b.ps. and dimethoxyethane is expensive. Ethanoic acid is too corrosive and smelly. Propanetriol is viscous and its M.W. is relatively high.

Commercial additives are usually ethanediol or ethanediol / methanol mixtures, with anti-oxidants and sometimes acid sensitive dyes added. The oral toxicity of ethane-diol and methanol is not a serious disadvantage. Spillage on hands can be washed off with water.

Ethanol boils about the same temperature as heptane and does not freeze. It is soluble in alkanes. It is no more hazardous than heptane and can be handled in the same ways (unlike coal or hydrogen).

Ethanol combustion produces about 70% as much heat per litre as petrol combustion. It burns well in vehicle engines producing almost no atmospheric pollutants and, in engines designed to burn petrol, 10% ethanol can be added to the petrol without carburettor changes.

The increasing cost of petroleum and gas, and the energy requirements of cracking to ethene make production by fermentation for all purposes, but primarily as a fuel, economically viable. The problem is particularly acute in industrialised nations with few petroleum deposits e.g. Europe, South Africa, South America or Australia.

Sunlight is free and the supply will not be exhausted soon. Production by fermentation requires biomass (cellulose, starch etc) to ferment and suitable enzymes to bring about the conversion to ethanol.

Recommendations to the company might be to -

a) buy land in a country where there is plenty of sun and cheap land
b) do research on which plants produce the most dry fermentable matter per square kilometer per day with minimal fertiliser (N, P and K) consumption
c) do research on strains of fermenting bacteria to maximise ethanol production from the biomass with minimum energy demand
d) persuade governments to adjust their taxation of alcohol and petroleum.

All this has already been started in Brazil which has very little oil but plenty of land and sun. Most of the 'petrol' there now contains 10% ethanol made by fermentation of cane sugar and it is hoped that, by the year 2000, 2% of Brazil's land area will supply about 75% of the country's motor fuel needs.

(A different approach is to grow plants (peanuts or sunflowers) which produce an oil which can replace deisel fuel.)

Reference: N.P. Cheremisinoff - Gasohol for Energy Production, Ann Arbor Science, 1979.

The routes to the products are as follows:-

Methanol

Relative Price = 1

methane ⟶ synthesis gas ⟶ methanol

Since the raw material is obtainable cheaply in a relatively high state of purity and the separation of the product is simple, methanol is relatively cheap.

Ethanol

Relative Price = 6

alkanes ⟶ ethene ⟶ ethanol

The production of ethene from alkanes is energy intensive (high temperature cracking).
Side products (e.g. propene) are produced but these are marketable, e.g. to make propanone or polypropene.

Ethanoic Acid

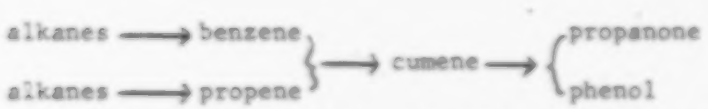
Relative Price = 13

alkanes ⟶ ethanoic acid

The separation of ethanoic acid from methanoic and propanoic acids by distillation adds to the expense of its production. The substances are all corrosive and the other acids are of lower market value.

Propanone

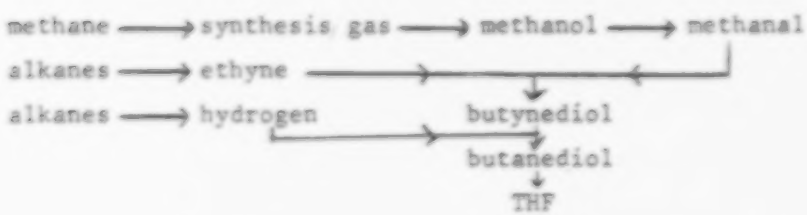
Relative Price = 6



Since phenol is a highly marketable by-product of the propanone synthesis, the price of propanone can be kept low.
The toluene and xylenes formed along with benzene are also valuable, e.g. to make polyester fibre.

THF

Relative Price = 37



The high relative price of THF is mainly a result of the complexity of its synthesis.

References

Petrochemicals Today, J.P. Stern & E.S. Stern, Edward Arnold, 1971.

Industrial Products, Tedder, Nechvatal & Jubb, Wiley, 1975.

Industrial Organic Chemistry, K. Weissermel & H-J Arpe, Verlag Chemie, 1978.

Criteria for selection of a suitable liquid.

These will include:

1. Since the iron is to be extracted as an ion-pair, the extracting liquid should be polar.

2. The organic liquid must be immiscible with water, or have an extremely low solubility in water.

3. To aid rapid separation of the layers, there should be as great a density difference as possible between the water layer and the organic layer.

4. For the same reason, the organic liquid should not be too viscous.

5. The liquid must not be too volatile since it is to be used in a tropical country; however, it must be capable of being evaporated off and, if possible, recovered for reuse.

6. The liquid should not be extremely expensive or poisonous.

7. Since the liquid is to be used in contact with acid, it must not be affected by acid.

ethanal	unsuitable - soluble in water
acetone	unsuitable - soluble in water
ethanoic acid	unsuitable - soluble in water
butan-1-ol	unsuitable - slightly soluble in water and might react with an acid
ethyl ethanoate	unsuitable - main problem is that it is slightly soluble in water and, being an ester, would be hydrolysed (slowly) by an acid
di-iso propyl ether	this is the solvent usually used; it represents a compromise among all the necessary features listed above
diethyl ether	this might also be of use, but is rather soluble in water and is much more volatile than the above ether and has an even lower flash point
toluene	has many desirable features but unfortunately is not very polar and does not extract the complex ion pair.

Solvent Properties (Criteria)

The solvent should:-

1. be miscible with hydrocarbons
2. be a good solvent for the polar nitrocellulose
3. be cheap
4. be volatile (but not too volatile that the paint dries too quickly). The volatility should be about the same as toluene.
5. have a high flash point to reduce fire hazards for the operator
6. have a low toxicity so as again to reduce risks for the operator
7. have a low viscosity so as to pass easily through the spray gun.

Conclusions.

Methanol is not soluble in alkanes but is soluble in toluene.

Ethanediol is soluble in neither and is non-volatile and viscous.

Cyclohexanol is too high boiling and too viscous.

Diethyl ether is too volatile, too flammable and not a very good solvent for the cellulose nitrate (relatively low dipole moment).

The Propanol, Butanone, Methylbutyl ethanoate and Methyl pentanone have suitable polarity, viscosity, boiling point and toxicity, have flash points which are not too low and are not very expensive.

There is no one correct answer.

The solvents used as co-solvents are mixtures of esters, e.g.

butyl ethanoate or 3-methylbutyl ethanoate (approx 40%)

and alcohols, e.g. propan-2-ol and alkanones, e.g. butanone, which make up approximately 20% of the total solvent mixture.

ORGANIC LIQUIDS CONTAINING OXYGEN

Pupils Copy

PUPIL

APPLICATIONS OF ORGANIC LIQUIDS CONTAINING OXYGEN

Introduction.

You already know some of the typical reactions and properties of alcohols, ethers, aldehydes, ketones and esters and may know something of the commercial importance and uses of some of these.

This package provides you with a Table of Data on physical properties, price and toxicity of some twenty such compounds and of hexane and toluene.

Use these data plus your previous knowledge as the basis for the discussions and decisions introduced below. The aim is not necessarily to arrive at a "right answer" but rather to think of the factors which would affect the choice.

The flash point is the minimum temperature at which the vapour enclosed above a liquid will be ignited by a flame and the liquid continue to burn.

The dipole moment is a measure of the polarity of the substance. The higher the dipole moment the more polar the substance. Hexane and toluene have low dipole moments.

The TLV (threshhold limit value) is the maximum concentration of the gas or vapour in the atmosphere which is considered safe for a person to work in regularly.

The prices are relative to the price of the same weight of methanol, taken as 1.

Discussion Topics		Colour
1)	Antifreeze	pink
2)	Ethanol production	white
3)	Solvent prices	yellow
4)	Iron Extraction	green
5)	Paint solvents	blue

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water					X	X					X	X	X		X	X	X	X			X	X
methanol																					X	
ethanol																						
propanol																						
butanol	X																					
cyclohexanol	X																					
ethanediol											X	X	X		X	X	X	X			X	X
propanetriol										X	X	X	X		X	X	X	X		X	X	X
ethanal																						
propanone								X														
butanone	X						X	X														
methylpentanone	X						X	X														
cyclohexanone	X						X	X														
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tetrahydrofuran																						
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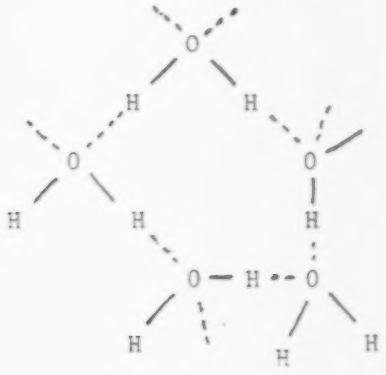
The cooling system of the motor car consists of a radiator connected by hoses to the engine. Approximately 50 litres of water circulate round the engine, through spaces around the cylinder block and back to the radiator. The water may rise to a temperature close to 100°C when the engine is hot. It is cooled by the air flowing through the radiator.

In very cold weather when the air temperature drops to 0°C or below, the water in the cooling system may freeze. The ice occupies a greater volume than the liquid water as the molecules of water settle into an open rigid cage-like structure i.e. the ice is less dense than the water.



This increase in volume occurring in the confined spaces around the cylinder block exerts such force on the metal that the casing may crack thus destroying the engine.

The formation of ice may be prevented by adding a suitable substance to the water, since the resulting solution will have a freezing point below 0°C. For many years ethane – 1, 2 – diol (ethylene glycol) was the most widely used anti-freeze material in car cooling systems. However because it is a petroleum product, its price increased rapidly as a result of the energy crisis in the 1970's. Manufacturing companies looked for an alternative. Ionic substances were useless since they caused serious corrosion problems. Organic solvents seem more suitable as additives but careful consideration of their properties is essential before a decision can be made about which ones are of most use.

A suitable additive

The data table has information about many organic substances. Study the data for the following substances and try to decide which would be the best anti-freeze;

Methanol	Propane-1,2,3-triol
Propanone (acetone)	Ethanoic acid
Ethane-1,2-diol	Ethyl ethanoate
Propan-2-ol	1,2-Dimethoxyethane

You may find it helpful to consider the following aspects of each solvent.

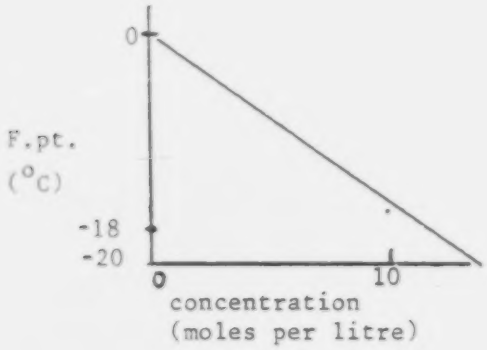
Miscibility - The substance must be completely miscible with water, but it must not react with the water or the metal or rubber parts of the cooling system.

Boiling Point - The substance must not have too low a boiling point or it may be lost by evaporation.

Flash Point - This must not be too low or there is a danger of fire.

Formula Mass

The amount of depression of the freezing point depends on the number of molecules of solute added and not on the weight of solute or type of molecule. Thus for a given weight of materials, light molecules are more effective than heavy molecules (more molecules per gram).



The graph shows the relationship between the moles of substance added and the lowering of the freezing point.

Expense - The relative prices per gram are shown in the table.

Other factors may appear to you to be important too.

DECISION

When you have considered the relative merits of the substances in the list suggested, you should try to decide on the most suitable one for use as anti-freeze. It may help you to decide if you draw up a table containing your list of solvents and their properties and assess their suitability as an anti-freeze by giving a star rating.

Imagine you are the Research & Planning Director for a multi-national chemical corporation.

You know that before 1940 ethanol was mainly made by fermentation of sugars made by hydrolysis of starch or cellulose

$$C_6H_{12}O_6 \xrightarrow{\text{enzymes}} 2\ C_2H_5OH + 2CO_2$$

and was used mainly as a beverage and as a fuel for stoves and engines.

(Many German vehicles during the 1939-45 war ran on ethanol from potatoes. Ethanol burns cleanly in a vehicle engine producing about 70% as much energy per litre as petrol and up to 10% can be added to petrol without requiring any carburettor adjustment.)

Since then fermentation production for human consumption has continued but production from petroleum via ethene,

$$\text{low molecular weight alkanes} \xrightarrow{\text{cracking}} CH_2 = CH_2 \xrightarrow[(H^+ \text{ catalyst})]{H_2O} C_2H_5OH$$

for use as a solvent or intermediate in the manufacture of other chemicals, has increased enormously.

You foresee that production by fermentation for use as a fuel is likely to become important again.

Make a list of the physical and chemical properties of ethanol which make it a suitable motor fuel.

What factors are likely to cause renewed interest in production of ethanol from carbohydrates rather than ethene?

Which countries in the world have little oil of their own but would be suitable for growing lots of plant material cheaply to turn into motor fuel?

What action would you recommend to your Board of Management and your chemical and biological research managers so that your company would prosper by investment in those countries?

PUPIL

SOLVENT PRICES

Imagine that you have joined a small chemicals company as a trainee marketing manager. You have a list of chemicals and their prices, but cannot understand why there should be such differences in the prices. In particular, you wonder why the relative prices of these compounds are as follows:-

Ethanoic acid	13 cost units
Ethanol	6
Tetrahydrofuran	37
Propanone	6
Methanol	1

Your boss provides you with an outline (next two pages) of the industrial synthesis of some petrochemicals and lists some of the factors which affect the cost of manufacture as follows:-

1. The cost of the starting material. Most of the substances to be considered are derived from petroleum fractions and natural gas.

2. The energy requirements of the process. Many reactions are exothermic. If heat produced in one part of the process can be re-used in another part of the synthesis, then the process as a whole is more economical. Highly endothermic processes may be expensive.

3. The use of high pressures in reactions requires specially strengthened plant and the maintenance of high pressures requires energy to compress the materials.

4. Suitable catalysts will reduce the energy requirement of a given process. If the catalyst is cheap and/or can be used for a long time without regeneration, the process may be more economical than one which requires a more expensive catalyst.

5. Highly corrosive products will require more specialised plant as well as more complex packaging.

6. Multiple stage synthesis increase costs. The more steps there are in a process, the lower will be the overall yield of final product and the greater will be the cost of reagents and plant.

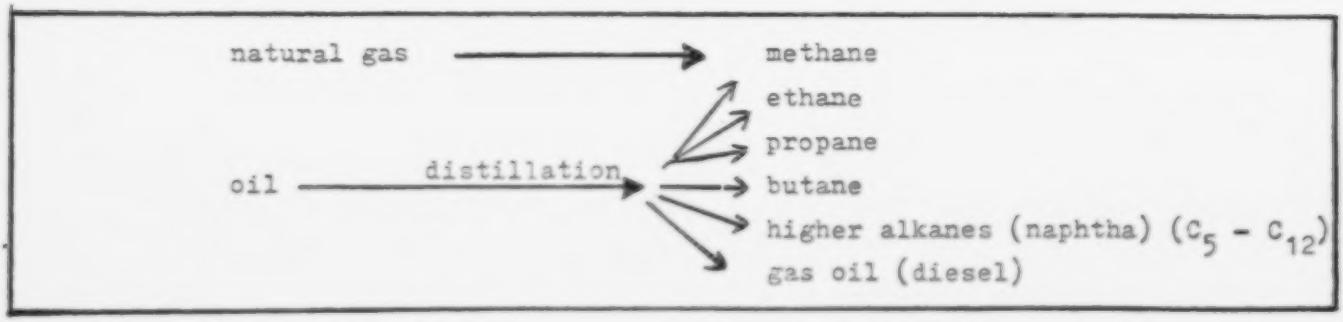
7. Low conversion of reagents to products e.g. on passing a mixture of gases over a catalyst may be overcome by passing the mixture several times but this may increase costs.

8. Side products of the desired reaction or of competing reactions may be valuable or may be a useless waste of starting material.

9. Separation of products from one another or from unchanged starting material must be done as economically as possible, e.g. by heating or cooling to boil one off or condense one out.

Make out a scheme for the synthesis of each of the five substances and try to relate the final price of each to the factors suggested.

Details of Synthetic Routes to Organic Liquids



alkanes (butane or naphtha) + steam $\xrightarrow[\text{brief exposure to high temperature, no catalyst}]{1050^\circ C}$ { ethyne, ethene, propene + other alkenes. (proportions depend on temp. used)

The mixture of unsaturated products is separated by distillation.

alkanes + O_2 $\xrightarrow[\text{highly exothermic}]{150^\circ C/50 \text{ atm.}}$ { methanoic acid, **ethanoic acid**, propanoic acid

The mixture of alkanoic acids is separated by distillation.

Corrosive products require special containers.

ethene + H_2O $\xrightarrow{\text{repeated passes at } 300^\circ C \text{ over } H_3PO_4 \text{ catalyst}}$ **ethanol**

After each pass over the catalyst the ethanol and some water are condensed out by cooling.

$CH_4 + H_2O \xrightarrow[1000 \text{ atm.}]{700^\circ C;\ NiO;} CO + 3H_2$ (endothermic)

$CH_4 + \frac{1}{2}O_2 \longrightarrow CO + 2H_2$ (exothermic)

Mixtures of controllable composition containing hydrogen, carbon monoxide with some carbon dioxide and nitrogen are made by high temperature reactions of alkanes or coal with air or steam. The mixtures of products are called synthesis gas.

contd.....

$CO + 2H_2$ —(400°C ; 340 atm.; ZnO/Cr_2O_3 catalyst; slightly exothermic)→ **methanol**

methanol condenses on cooling; unreacted gas is recycled.

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methanol + $\frac{1}{2}O_2$ —(slightly exothermic)→ methanal + water

methanol —(silver or copper catalyst; slightly endothermic)→ methanal + hydrogen

---

$C_6 - C_8$ alkanes and cycloalkanes —(catalytic reforming)→ H_2 + {benzene, toluene, xylenes}

The benzene, toluene and xylenes are separated from the unchanged alkanes by solvent extraction.

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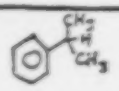
benzene + propene —(40°C ; H_2SO_4 catalyst)→ cumene 

cumene —(oxygen then acid catalyst)→ phenol + **propanone**

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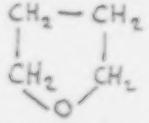
ethyne + methanal —(Cu_2C_2; 100°C ; 5 atm.)→ 1,4 dihydroxybut-2-yne

↓ H_2; 100°C; 300 atm. Ni cat

1,4 dihydroxybutane

↓ 120°C; H_3PO_4 catalyst



tetrahydrofuran (THF)

THF, which has a low boiling point, is distilled continuously out of the mixture as it is formed.

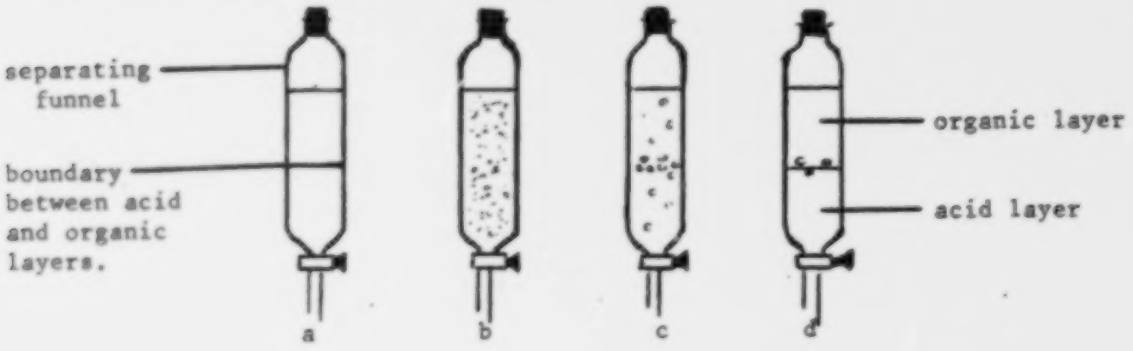
PUPIL

IRON EXTRACTION

Imagine that you have the responsibility of setting up a laboratory in a relatively poor tropical country to analyse minerals for iron. You plan to use the following procedure which takes advantage of the fact that iron (III) can be extracted into organic solvents leaving most other metal ions behind in an aqueous solution.

The iron mineral is treated with aqueous HCl. The iron in it is converted to an ion pair with the formula $H^+FeCl_4^- xH_2O$ where x is 4 or 5. The acid solution containing the ion pair is then shaken with an organic liquid in a separating funnel. The iron-containing ion pair is extracted into the organic liquid; that is, the iron leaves the acid solution and enters the organic liquid. This is done by shaking the two liquids together and allowing them to separate again into two layers. The organic liquid is then drawn off. The organic solvent is evaporated off. The iron content of the residue can be established by titration or colorimetry.

The extraction procedure is illustrated below.



a) The acid layer and organic layer are in the funnel which has not yet been shaken.

b) The funnel has been shaken; the layers have mixed but have not started to separate yet.

c) The two layers are beginning to separate; globules of acid move down through the organic layer and globules of organic liquid are moving up through the acid layer.

d) Separation is almost complete. When separation is complete, the tap is opened to remove the acid layer.

You have to decide which organic liquid would be most suitable for the process, having regard to the conditions under which the work is to be done, and to the convenience of the process. List the properties you would need in an ideal solvent for this process. Use your list to assess the suitability of each of the solvents given below and decide which one(s) fit best.

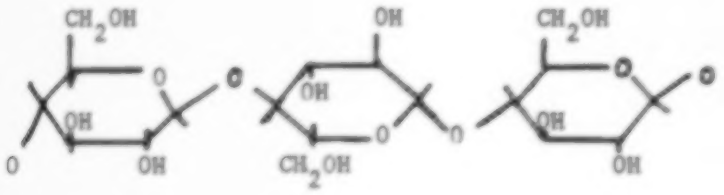
Liquids available	
ETHANAL	ACETONE
ETHANOIC ACID	ETHANOL
BUTAN-1-OL	ETHYL ETHANOATE
DI-ISOPROPYL ETHER	DIETHYL ETHER
TOLUENE	

PUPIL

PAINT SOLVENTS

Many car body spray paints consist of solutions of the ester, cellulose nitrate, in a mixture of solvents.

Cellulose, a macromolecule of the carbohydrate family, is built up by the condensation polymerisation of glucose molecules and the molecule can be as follows:-



Cellulose

There are many hydroxy groups within the cellulose molecule which, like any other organic hydroxy group, will react with an acid under appropriate conditions to produce an ester. If the esterification agent used with cellulose is nitric acid, the product formed is cellulose nitrate. Cellulose nitrate is a <u>solid</u> at room temperature and the molecule is a covalent polymer with many polar groupings.

When the solution of cellulose nitrate is sprayed on to the car body, the solvent evaporates leaving behind a thin surface film of the solid cellulose nitrate. The solvent is usually a mixture containing about 40% of saturated, unsaturated and aromatic hydrocarbons. The remaining 60% is made up of a liquid which is known as the co-solvent. The main function of the co-solvent is to help dissolve the cellulose nitrate.

Your task is to select an appropriate solvent from the list below which can be used as a suitable co-solvent in the manufacture of car body spray paint. In arriving at your decision you will need to consider many factors of which only <u>some</u> are listed below e.g.

the <u>miscibility</u> (mixing ability) of the solvent with hydrocarbons

the <u>suitability</u> of the solvent in dissolving the moderately polar cellulose nitrate

the <u>viscosity</u> of the solvent, because if it is too high it will not pass easily through the nozzle of the spray gun

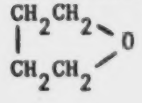
<u>Possible method</u>.

1. Make a list of suitable properties (criteria) required for the solvent.e.g. miscibility, cost etc.

2. With the aid of your list pick out <u>three</u> solvents which meet most of your criteria. It is unlikely you will find a solvent which meets all your criteria.

Methanol
Propan-2-ol
Cyclohexanol
Butanone
Ethanediol
3-methylbutyl ethanoate
4-methylpentan-2-one
Diethyl ether

	MW	bp (°C)	mp (°C)	Flash point(°C)	Viscosity (η)	Dipole Moment(μ)	Solubility in water	TLV (ppm)	Relative price	
Methanol	32	65	-94	10	0.55	2.87	∞	200	1	Toxic orally
Ethanol	46	78	-117	12	1.1	1.66	∞	1000	6	Toxic orally after repeated ingestion
Propan-2-ol	60	82	-90	12	2.8	1.66	∞	400	6	
Butan-1-ol	74	117	-90	24			8g/100g	50 (100)	6	Toxic orally
cyclohexanol	100	161	25	-	50	1.86	4g/100g	50	28	
Ethane-1,2-diol (Ethylene glycol)	62	197	-11	-	22	2.3	∞	100 (50)	9	Toxic orally
Propane-1,2,3, triol (Glycerol)	92	290	20	-	1412		∞		22	Not toxic
Ethanal (Acetaldehyde)	44	21	-121	-38			∞	100	9	Nasty odour. Polymerises on keeping.
Propanone (Acetone)	58	56	-95	-18	0.3	2.7	∞	1000 (750)	6	
Butanone (Methyl ethyl ketone)	72	80	-86	-7	0.4	2.7	26g/100g	200	6	

4-Methyl pentan-2-one (Methyl isobutyl ketone)	100	116	-84	17	0.5	—	1.7g/100g	100 (50)	9	
Cyclohexanone	98	156	-16	44	2.2	3.0	2g/100g	50 (25)	18	
Ethanoic acid	60	118	17	43			∞	10	13	
Ethyl ethanoate (ethyl acetate)	88	77	-83	-4	0.4	1.88	8g/100g	400	12	
3-methyl butyl ethanoate (Isoamyl acetate)	130	142	-78	23	—	—	2g/100g	100	16	
Diethyl ether	74	35	-116	-45	0.24	1.15	8g/100g	400	7	Anaesthetic at > 5% v/v in air. Toxic at > 10%
Diisopropyl ether	102	69	-85	-28	0.33	1.22	1g/100g	250	6	
Oxolan(Tetra-hydrofuran) 	72	66	-108	-17	0.55	1.75	∞	200	37	
1,2-Dimethoxy ethane (Dimethyl cellosolve)	90	85	-58	4	0.45	1.7	∞	—	30	
Hexane	86	69	-95	-23	0.3	0.1	insol.	100(≤0)	2	narcotic vapour
Toluene	92	111	-95	4	0.6	0.3	insol.	100	2	narcotic vapour

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